CLAIMS

We claim:

1. A method of forming a powder metal material comprising:

    molding a powder metal composition into a compact;

    sintering the compact;

    at least one of peening and surface rolling at least a portion of a surface of the compact after sintering to densify the at least a portion of the surface; and

    sizing the compact after shot peening to densify at least a portion of a core region of the compact.

2. The method of claim 1 wherein the powder metal material comprises iron.

3. The method of claim 1 wherein the powder metal material comprises iron and at least one alloying element chosen from nickel, molybdenum, chromium, manganese, copper, and phosphorus.

4. The method of claim 1 wherein the powder metal material is an iron-base powder metal material having a sintered carbon content ranging from 0.02 weight percent to 0.6 weight percent.

5. The method of claim 1 wherein peening comprises at least one of shot peening and laser peening.

6. The method of claim 1 wherein after sintering, at least a portion of the surface of the sintered compact is shot peened to densify the at least a portion of the at least one surface.

7. The method of claim 6 wherein shot peening the at least a portion of the surface of the sintered compact comprises impacting the at least a portion of at least one surface with shot having a diameter ranging from 0.005 inches to 0.331 inches.

8. The method of claim 6 wherein shot peening the at least a portion of the surface of the sintered compact comprises impacting the at least a portion of at least one surface with shot having a diameter ranging from 0.014 inches to 0.046 inches.

9. The method of claim 6 wherein shot peening the at least a portion of the surface of the sintered compact comprises impacting the at least a portion of at least one surface with shot for a shot time ranging from 5 minutes to 45 minutes.

10. The method of claim 6 wherein immediately after shot peening, the at least a portion of the surface of the sintered compact that was shot peened is uniformly densified to a density of at least 98 percent of a theoretical density of the powder metal material to a depth ranging from 0.001 inches to 0.040 inches.

11. The method of claim 6 wherein immediately after shot peening, the at least a portion of the surface of the sintered compact that was shot peened is uniformly densified to a density of at least 98 percent of a theoretical density of the powder metal material to a depth of at least 0.002 inches.

12. The method of claim 6 wherein immediately after shot peening, the at least a portion of the surface of the sintered compact that was shot peened is uniformly densified to a density of at least 98 percent of a theoretical density of the powder metal material to a depth of at least 0.005 inches.

13. The method of claim 6 wherein immediately after shot peening, the at least a portion of the surface of the sintered compact that was shot peened is uniformly densified to a density of at least 98 percent of a theoretical density of the powder metal material to a depth of at least 0.010 inches.

14. The method of claim 6 wherein immediately after shot peening, the at least a portion of the surface of the sintered compact that was shot peened is uniformly densified to full density to a depth ranging from 0.001 inches to 0.040 inches.

15. The method of claim 1 wherein after sizing, the at least a portion of the core region of the compact has a density of at least 92 percent of a theoretical density of the powder metal material.

16. The method of claim 1 further comprising pre-sintering the compact after molding and prior to sintering.

17. The method of claim 1 further comprising at least one of (i) quenching and tempering the compact after sizing and (ii) carburizing the compact after sizing.

18. The method of claim 17 further comprising at least one of shot peening, surface rolling, and honing at least a portion of a surface of the compact to introduce compressive stresses into the at least a portion of the surface of the compact after sizing the compact.

19. The method of claim 1 further comprising plating at least a portion of the surface that was densified after sizing the compact.

20. A method of forming a powder metal material comprising:

molding a powder metal composition into a compact;

sintering the compact;

at least one of peening and surface rolling at least a portion of a surface of the compact after sintering to densify the at least a portion of the surface; and

forging the compact to densify at least a portion of a core region of the compact.

21. The method of claim 20 wherein peening comprises at least one of shot peening and laser peening.

22. The method of claim 20 wherein after sintering, at least a portion of the surface of the sintered compact is shot peened to densify the at least a portion of the surface.

23. The method of claim 22 wherein shot peening the at least a portion of the surface of the sintered compact comprises impacting the at least a portion of the surface with shot having a diameter ranging from 0.005 inches to 0.331 inches.

24. The method of claim 22 wherein shot peening the at least a portion of the surface of the sintered compact comprises impacting the at least a portion of the surface with shot having a diameter ranging from 0.014 inches to 0.046 inches.

25. The method of claim 22 wherein shot peening the at least a portion of the surface of the sintered compact comprises impacting the at least a portion of the surface with shot for a shot time ranging from 5 minutes to 45 minutes.

26. The method of claim 22 wherein immediately after shot peening, the at least a portion of the surface of the sintered compact that was shot peened is uniformly densified to a density of at least 98 percent of a theoretical density of the powder metal material to a depth ranging from 0.001 inches to 0.040 inches.

27. The method of claim 22 wherein immediately after shot peening, the at least a portion of the surface of the sintered compact that was shot peened is uniformly densified to at a density of least 98 percent of a theoretical density of the powder metal material to a depth of at least 0.002 inches.

28. The method of claim 22 wherein immediately after shot peening, the at least a portion of the surface of the sintered compact that was shot peened is uniformly

densified to a density of at least 98 percent of a theoretical density of the powder metal material to a depth of at least 0.005 inches.

29. The method of claim 22 wherein immediately after shot peening, the at least a portion of the surface of the sintered compact that was shot peened is uniformly densified to a density of at least 98 percent of a theoretical density of the powder metal material to a depth of at least 0.010 inches.

30. The method of claim 22 wherein immediately after shot peening, the at least a portion of the surface of the sintered compact that was shot peened is uniformly densified to full density to a depth ranging from 0.001 inches to 0.040 inches.

31. The method of claim 20 wherein after forging, the at least a portion of the core region of the compact has a density of at least 98 percent theoretical density of the powder metal material.

32. The method of claim 20 wherein after forging, the at least a portion of the surface of the compact that was densified is essentially free of finger oxides.

33. The method of claim 20 further comprising pre-sintering the compact after molding and prior to sintering.

34. The method of claim 20 further comprising reheating the compact prior to forging the compact.

35. The method of claim 20 further comprising at least one of (i) quenching and tempering the compact after sizing and (ii) carburizing the compact after forging.

36. The method of claim 35 further comprising at least one of shot peening, surface rolling, and honing at least a portion of a surface the compact to introduce compressive stresses into the at least a portion of the surface of the compact.

37. The method of claim 20 further comprising plating at least a portion of the surface that was densified after forging the compact.

38. A method of forming an iron-base powder metal part chosen from a gear and a sprocket, the method comprising:

molding a powder metal composition into a green part comprising at least one tooth having a root region and a flank region;

sintering the green part; and

subsequent to sintering the green part, shot peening at least a portion of an as-sintered surface in at least one of the tooth root region and the tooth flank region to uniformly densify the at least a portion of the as-sintered surface to full density to a depth of at least 0.001 inches.

39. The method of claim 38 wherein at least a portion of a core region of the iron-base powder metal part has a density of at least 92 percent of a theoretical density of the iron-base powder metal part.

40. A method of forming a powder metal part comprising:

molding a powder composition into a green part comprising at least one tooth having a root region and a flank region;

sintering the green part;

subsequent to sintering the green part, shot peening at least a portion of a surface in at least one of the tooth root region and the tooth flank region to densify the at least a portion of the surface; and

sizing the part after shot peening to densify at least a portion of a core region of the part.

41. The method of claim 40 wherein the part is chosen from a gear and a sprocket.

42. The method of claim 40 wherein immediately after shot peening, the at least a portion of the surface of the sintered part that was shot peened is uniformly densified to a density of at least 98 percent of a theoretical density of the powder metal part to a depth ranging from 0.001 inches to 0.040 inches.

43. The method of claim 40 wherein immediately after shot peening, the at least a portion of the surface of the sintered part that was shot peened is uniformly densified to a density of at least 98 percent of a theoretical density of the powder metal part to a depth of at least 0.002 inches.

44. The method of claim 40 wherein immediately after shot peening, the at least a portion of the surface of the sintered part that was shot peened is uniformly densified to a density of at least 98 percent of a theoretical density of the powder metal part to a depth of at least 0.005 inches.

45. The method of claim 40 wherein immediately after shot peening, the at least a portion of the surface of the sintered part that was shot peened is uniformly densified to a density of at least 98 percent of a theoretical density of the powder metal part to a depth of at least 0.010 inches.

46. The method of claim 40 wherein immediately after shot peening, the at least a portion of the surface of the sintered part that was shot peened is uniformly densified to full density to a depth ranging from 0.001 inches to 0.040 inches.

47. The method of claim 40 wherein after sizing, the at least a portion of the core region has a density of at least 92 percent of a theoretical density of the powder metal part.

48. The method of claim 40 further comprising pre-sintering the part after molding and prior to sintering.

49. The method of claim 40 further comprising at least one of (i) quenching and tempering the compact after sizing and (ii) carburizing the part after sizing.

50. The method of claim 49 further comprising at least one of shot peening, surface rolling, and honing at least a portion of a surface the sintered part to introduce compressive stresses into the at least a portion of the surface of the part.

51. A method of forming a powder metal part comprising:

molding a powder metal composition into a part comprising at least one tooth having a root region and a flank region;

sintering the green part;

subsequent to sintering the green part, shot peening at least a portion of a surface in at least one of the tooth root region and the tooth flank region to densify the at least a portion of the surface; and

forging the part to densify at least a portion of a core region of the part.

52. The method of claim 51 wherein the part is selected from the group consisting of a gear and a sprocket.

53. The method of claim 51 wherein immediately after shot peening, the at least a portion of the surface of the sintered part that was shot peened has a density of at least 98 percent of a theoretical density of the powder metal part.

54. The method of claim 51 wherein immediately after shot peening, the at least a portion of the surface of the sintered part that was shot peened is fully dense.

55. The method of claim 51 wherein immediately after shot peening, the at least a portion of the surface of the sintered part that was shot peened is uniformly densified to a density of at least 98 percent of a theoretical density of the powder metal part to a depth ranging from 0.001 inches to 0.040 inches.

56. The method of claim 51 wherein immediately after shot peening, the at least a portion of the surface of the sintered part that was shot peened is uniformly densified to a density of at least 98 percent of a theoretical density of the powder metal part to a depth of at least 0.002 inches.

57. The method of claim 51 wherein immediately after shot peening, the at least a portion of the surface of the sintered part that was shot peened is uniformly densified to a density of at least 98 percent of a theoretical density of the powder metal part to a depth of at least 0.005 inches.

58. The method of claim 51 wherein immediately after shot peening, the at least a portion of the surface of the sintered part that was shot peened is uniformly densified to a density of at least 98 percent of a theoretical density of the powder metal part to a depth of at least 0.010 inches.

59. The method of claim 51 wherein immediately after shot peening, the at least a portion of the surface of the sintered part that was shot peened is uniformly densified to full density to a depth ranging from 0.001 inches to 0.040 inches.

60. The method of claim 51 wherein after forging, the at least a portion of the surface of the part that was shot peened is essentially free of finger oxides.

61. The method of claim 51 wherein after forging, the at least a portion of the core region of the part has a density of at least 98 percent of a theoretical density of the powder metal part.

62. The method of claim 51 wherein after forging, both the surface and the core region of the iron-base powder metal part have full density.

63. The method of claim 51 further comprising pre-sintering the compact after molding and prior to sintering.

64. The method of claim 51 further comprising at least one of (i) quenching and tempering the compact after forging and (ii) carburizing the part after forging.

65. The method of claim 64 further comprising at least one of shot peening, surface rolling, and honing at least a portion of the surface the part to introduce compressive stresses into the at least a portion of the surface of the part.

66. A method of forming a gear comprising:

molding a powder metal composition into a gear-shaped compact, the gear-shaped compact comprising at least one tooth having a root region and a flank region;

sintering the gear-shaped compact;

subsequent to sintering the gear-shaped compact, shot peening at least a portion of a surface in at least one of the tooth root region and the tooth flank region to densify the at least a portion of the surface; and

at least one of sizing the gear-shaped compact and forging the gear-shaped compact after shot peening to densify at least a portion of a core region of the gear-shaped compact.

67. The method of claim 66 further comprising decarburizing at least a portion of the compact after sintering and prior to shot peening the at least portion of the surface region.

68. A powder metal part made by:

molding a powder metal composition into a green powder metal part;

sintering the green powder metal part;

subsequent to sintering the green powder metal part, shot peening at least a portion of a surface of the sintered powder metal part to densify the at least a portion of the surface such that immediately after shot peening, the

at least a portion of the surface has full density to a depth of at least 0.001 inches; and

forging the powder metal part to densify at least a portion of a core region of the powder metal part;

wherein after forging, the at least a portion of the at least one surface of the powder metal part that was shot peened is essentially free of finger oxides and the at least a portion of the core region of the part has a density of at least 98 percent theoretical density of the powder metal part.

69. An iron-base powder metal part comprising a surface and a core, wherein both the surface and the core of the iron-base powder metal part have full density.

70. The iron-base powder metal part of claim 69 wherein the iron-base powder metal part is chosen from a gear and a sprocket.

71. The iron-base powder metal part of claim 70 wherein the iron-base powder metal part has a single tooth bending fatigue life of at least 3 million cycles at a bending stress of at least 160 ksi.

72. The iron-base powder metal part of claim 70 wherein the iron-base powder metal part has a single tooth bending fatigue life of at least 3 million cycles at a bending stress of at least 190 ksi.

73. The iron-base powder metal part of claim 70 wherein the surface of the iron-base powder metal part is essentially free of finger oxides.

74. An iron-base powder metal part comprising at least one tooth having a root region and a flank region, wherein at least a portion of a surface in at least one of the tooth root region and the tooth flank region is uniformly densified to full density to a depth of at least 0.002, and at least a portion of a core region of the iron-base

powder metal part has a density of at least 92 percent of the theoretical density of the iron-base powder metal part.

75. The iron-base powder metal part of claim 74 wherein the at least a portion of the surface in at least one of the tooth root region and the tooth flank region is uniformly densified to full density to a depth of at least 0.005 inches.

76. The iron-base powder metal part of claim 74 wherein the at least a portion of the surface in at least one of the tooth root region and the tooth flank region is uniformly densified to full density to a depth of at least 0.010 inches.

77. The iron-base powder metal part of claim 74 wherein the at least a portion of the core region has a density of at least 98 percent of the theoretical density of the iron-base powder metal part.

78. The iron-base powder metal part of claim 74 wherein the at least a portion of the core region of the part is fully dense.

79. A method of forming a component comprising:

providing a powder metal part comprising a surface and a core region, wherein at least a portion of the surface of the powder metal part is uniformly densified to full density to a depth of at least 0.001 inches, and at least a portion of the core region of the powder metal part has a density of at least 92 percent of the theoretical density of the powder metal part; and

joining at least a portion of the surface of the powder metal part that was uniformly densified to full density to a depth of at least 0.001 inches to at least a portion of at least one additional metal part by at least one of welding and brazing.

80. The method of claim 79 wherein the at least a portion of the surface of the powder metal part is uniformly densified to full density to a depth of at least 0.005.

81. The method of claim 79 wherein the at least a portion of the surface of the powder metal part is uniformly densified to full density to a depth of at least 0.010.

82. The method of claim 79 wherein the at least a portion of the core region of the powder metal part has a density of at least 98 percent of the theoretical density of the powder metal part.

83. The method of claim 79 wherein the at least a portion of the core region of the powder metal part is full density.

84. The method of claim 79 wherein obtaining the powder metal part comprises:

molding a powder metal composition into a compact;

sintering the compact;

subsequent to sintering the compact, shot peening at least a portion of a surface of the compact to densify the at least a portion of the surface; and

at least one of sizing the compact and forging the compact after shot peening to densify at least a portion of a core region of the compact.

85. A component comprising:

a powder metal part comprising a surface and a core region, wherein at least a portion of the surface of the powder metal part is uniformly densified to full density to a depth of at least 0.001 inches, and at least a portion of the core region of the powder metal part has a density of at least 92 percent of the theoretical density of the powder metal part; and

at least one additional part joined to at least a portion of the powder metal part by at least one of welding and brazing at least a portion of the at least one additional part to the at least a portion of the surface of the powder

metal part that was uniformly densified to full density to a depth of at least 0.001 inches.

86. The component of claim 85 wherein the at least a portion of the surface of the powder metal part is uniformly densified to full density to a depth of at least 0.005.

87. The component of claim 85 wherein the at least a portion of the surface of the powder metal part is uniformly densified to full density to a depth of at least 0.010.

88. The component of claim 85 wherein at least a portion of the core region of the powder metal part has a density of at least 98 percent of the theoretical density of the powder metal part.

89. A powder metal part comprising a densified surface that is gas-tight, wherein the densified surface is uniformly densified to full density to a depth of at least 0.001 inches.

90. The powder metal part of claim 89 wherein the densified surface is uniformly densified to full density to a depth of at least 0.005 inches.

91. The powder metal part of claim 89 wherein at least a portion of a core region of the powder metal part has a density of at least 92 percent of a theoretical density of the powder metal part.

92. The powder metal part of claim 89 wherein the powder metal part is chosen from an EGR valve, an exhaust system flange and an exhaust system seal.

93. A method of forming a powder metal part comprising:

forming a powder metal composition into a compact;

sintering the compact; and

shot peening at least a portion of an as-sintered surface of the compact such that immediately after shot peening, the at least a portion of the as-sintered surface is uniformly densified to full density to a depth of at least 0.001 and is gas-tight.

94. The method of claim 93 wherein at least a portion of a core region of the powder metal part has a density of at least 92 percent of a theoretical density of the powder metal part.

95. A powder metal part comprising a plated surface that is essentially free of sealing materials, wherein the plated surface is uniformly densified to full density to a depth of at least 0.001 inches.

96. The powder metal part of claim 95 wherein the plated surface is uniformly densified to full density to a depth of at least 0.005 inches.

97. The powder metal part of claim 95 wherein the plated surface that is essentially free of sealing materials is chosen from a chromium-plated surface and a zinc-plated surface.

98. The powder metal part of claim 95 wherein at least a portion of a core region of the powder metal part has a density of at least 92 percent of a theoretical density of the powder metal part.

99. A method of forming a plated, powder metal part that is essentially free of sealing materials comprising:

forming a powder metal composition into a compact;

sintering the compact;

shot peening at least a portion of an as-sintered surface of the sintered compact such that immediately after shot peening, the at least a portion of

the as-sintered surface of the sintered compact is uniformly densified to full density to a depth of at least 0.001 inches; and

plating at least a portion of the surface that is uniformly densified.

100. The method of claim 99 wherein at least a portion of a core region of the powder metal part has a density of at least 92 percent of a theoretical density of the powder metal part.